Dual-band altimetry for polar science and oceanography: the Copernicus CRISTAL mission

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OSTST 2022, Venice

The heritage from CryoSat

Radar altimetry almost all way to the poles!

- Established SAR-mode altimetry for good
- Showed benefits of SARIn
- Allowed the demonstration of FF-SAR (but closed burst)

A highly successful Earth Explorer,
has built the case and paved the way
to an operational mission for Copernicus

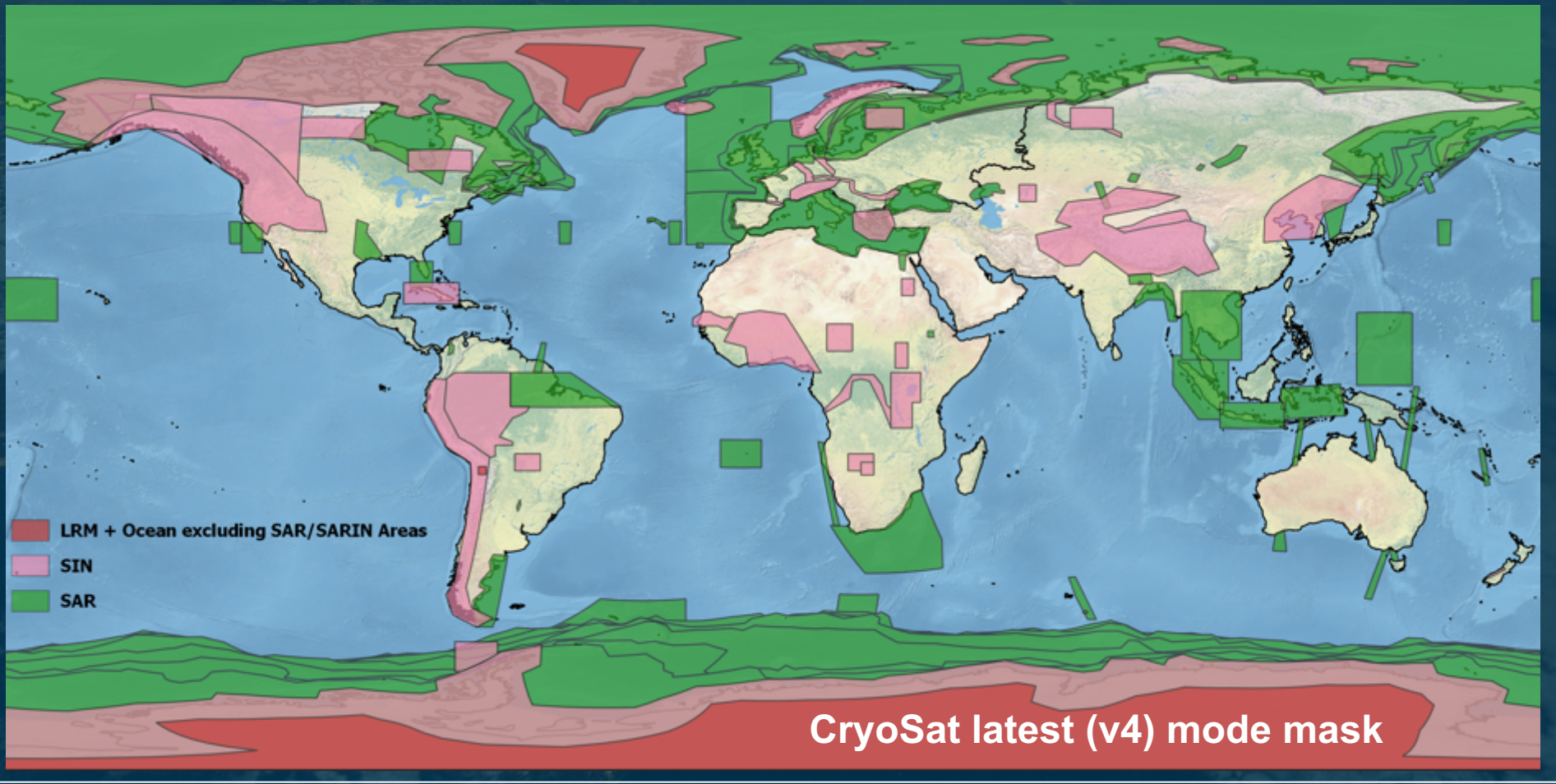
How do we make an even better CryoSat?

(in particular for the cryosphere, i.e. the primary mission objective)

1) Over ice, exploit interferometric mode in full

CryoSat only operates in SARin mode over part of the cryosphere

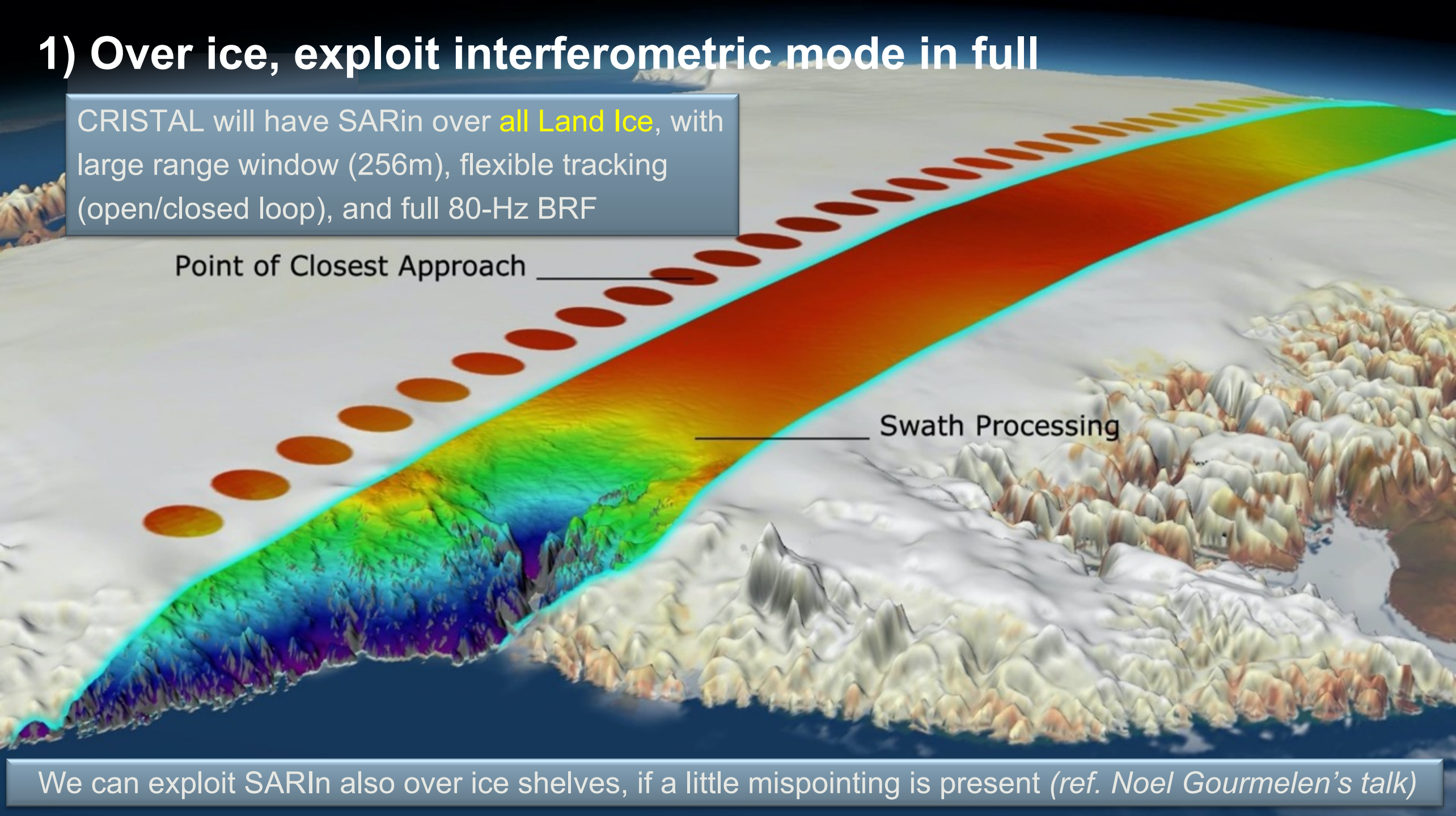
SARin frequency of bursts (BRF) is 21.4 Hz, i.e. only ¼ of SAR mode (85.7 Hz) → fewer multilooks → lower precision



CryoSat latest (v4) mode mask

1) Over ice, exploit interferometric mode in full

CRISTAL will have SARin over all Land Ice, with large range window (256m), flexible tracking (open/closed loop), and full 80-Hz BRF



We can exploit SARIn also over ice shelves, if a little mispointing is present *(ref. Noel Gourmelen's talk)*

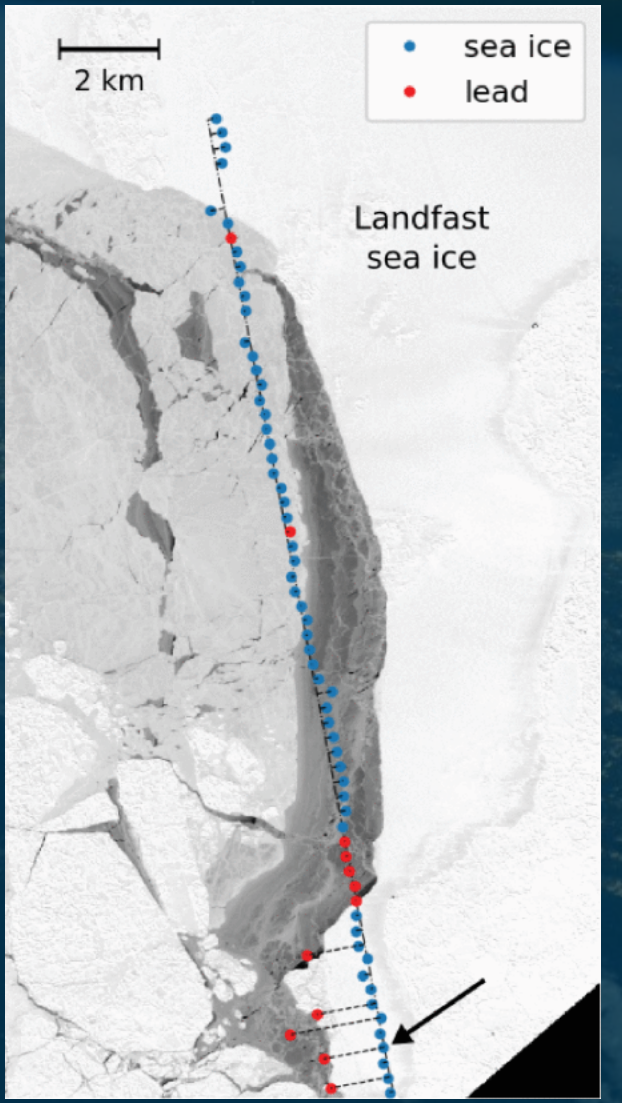
1) Over ice, exploit interferometric mode in full

We want SARin also over all Sea Ice

→ allows taking advantage of across-track leads

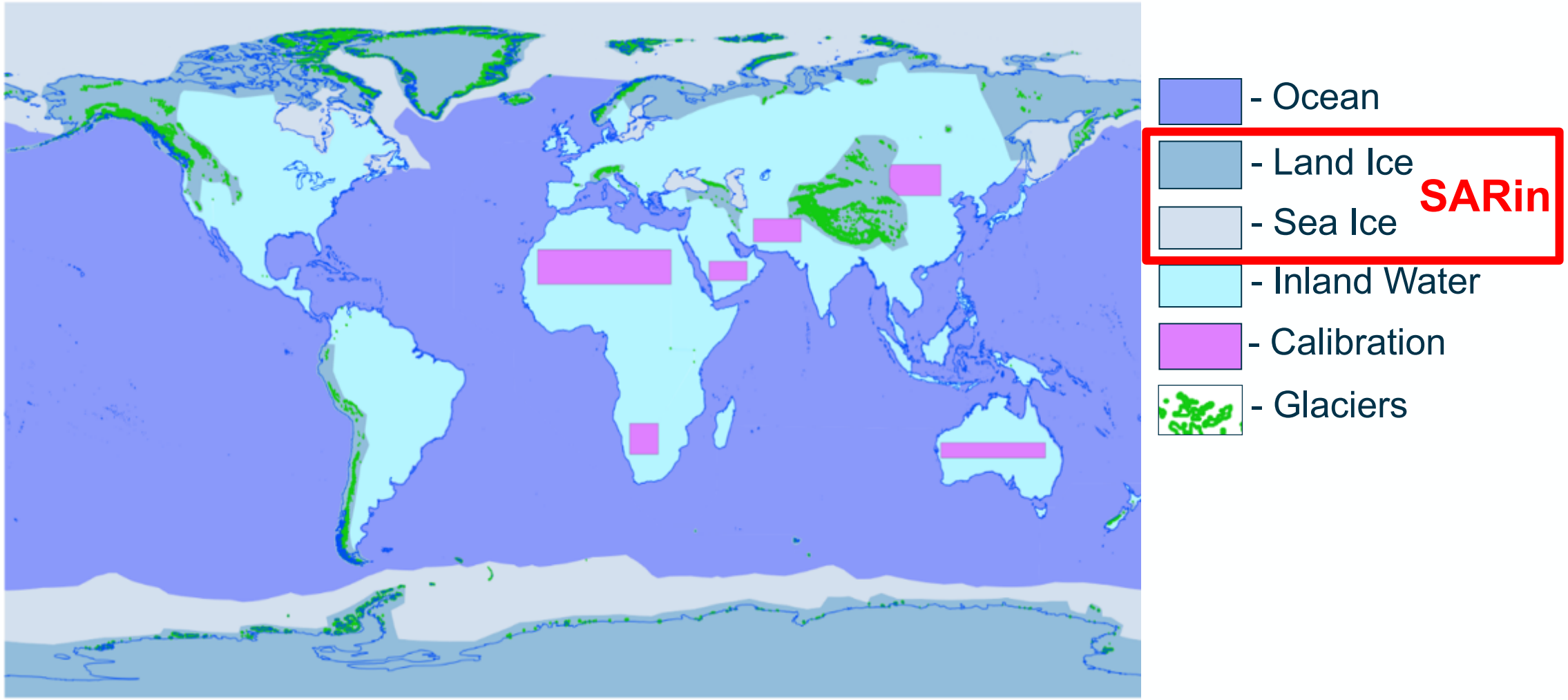
→ more precise SLA in ice-covered regions

→ lower uncertainty on ice freeboard and sea ice thickness



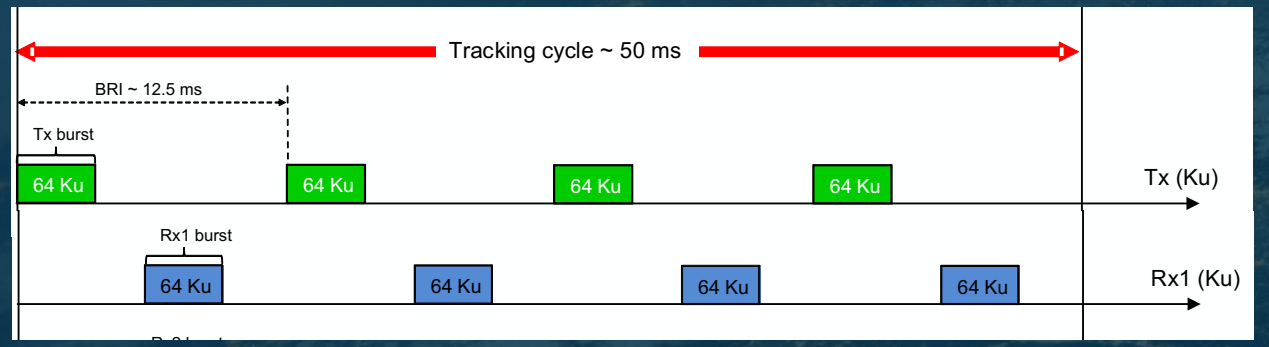
Di Bella et al, IEEE TGARS, 2021

CRISTAL → SARin over all land ice and sea ice

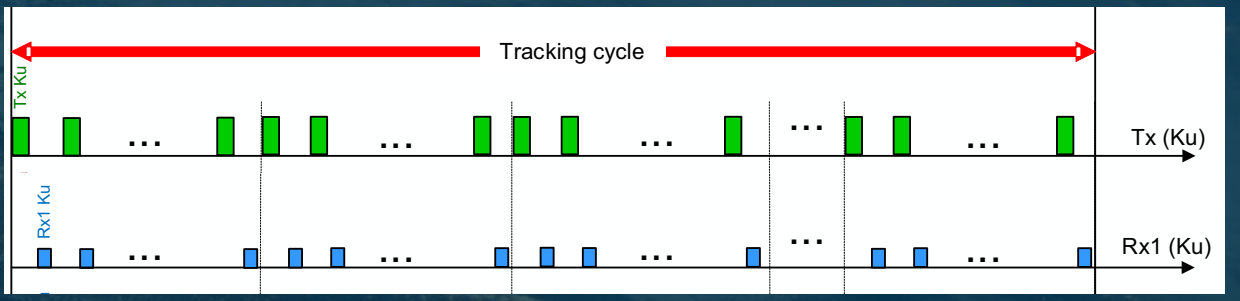


2) over Sea Ice, make it open burst

CLOSED BURST
4 bursts x 64 pulses = 256 pulses in 50 ms
~ 5k pulses/s



OPEN BURST
12 bursts x 64 pulses = 756 pulses in ~50 ms
~ 15k pulses/s



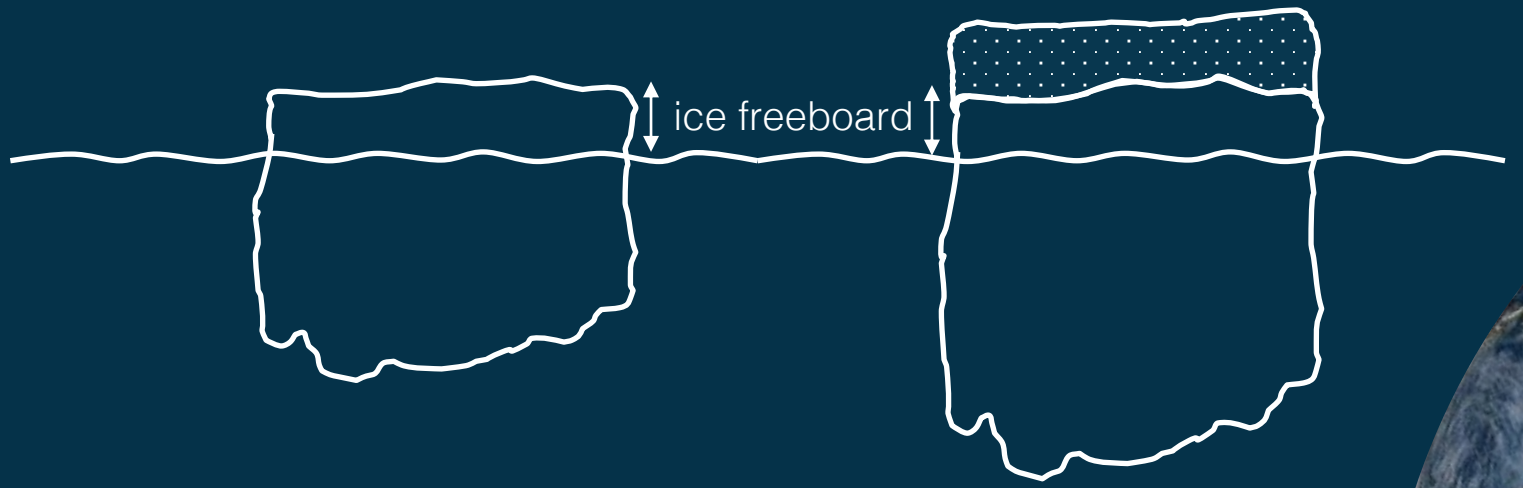
See poster by Mank et al. in Science IV Poster session

Increased precision – three times as many echoes!

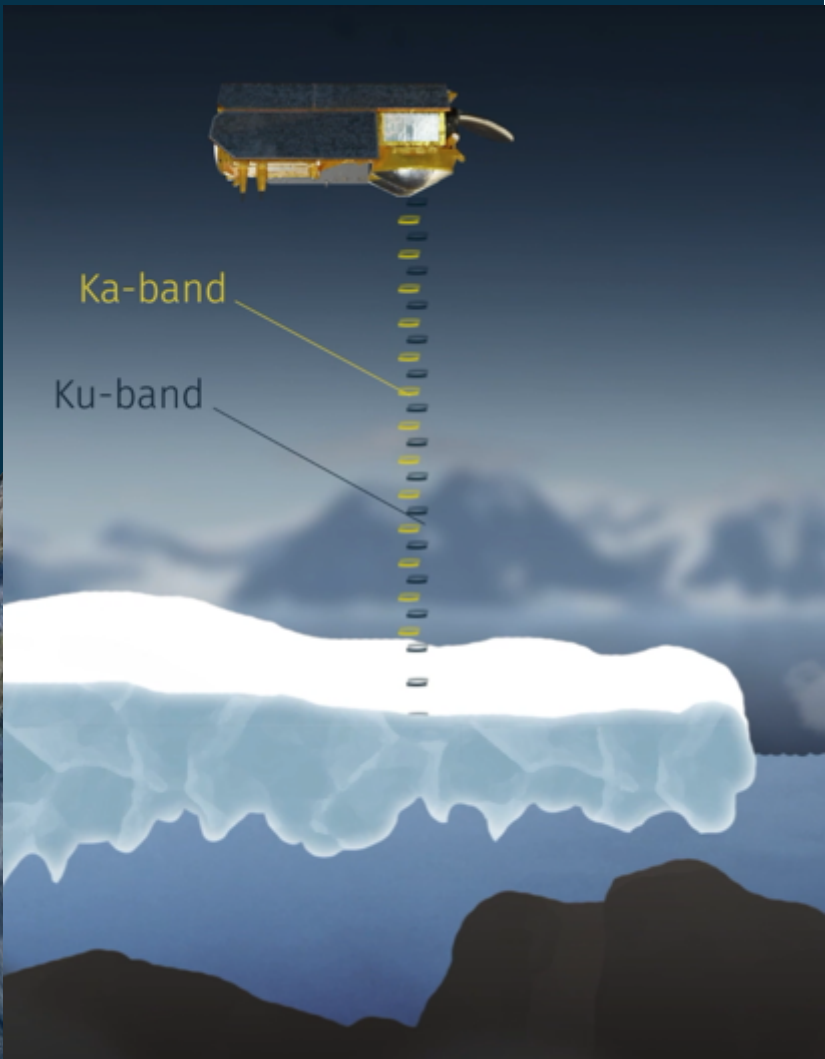
Continuous radar chronogram allows **proper Fully-Focused processing** → increased along-track resolution

3) Make it measure the snow depth → add the Ka-band

- Snow depth is important in itself - for local and global energy and freshwater budget
- Essential for retrieving sea ice thickness from altimetry

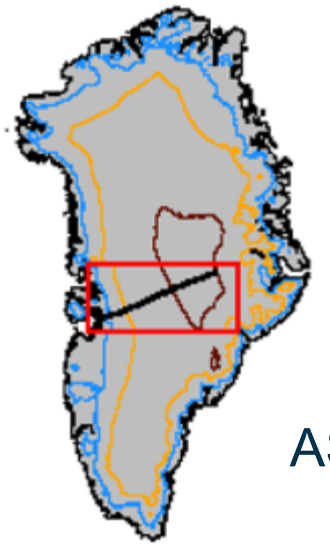


$$\text{Sea ice thickness} = \frac{f_i\,\rho w}{\rho_w - \rho_i} + \frac{h_s\,\rho_s}{\rho_w - \rho_i}$$



Credits: Isobel Lawrence et al., LPS22

Dual-band to explore snow/firn/ice interfaces: an example



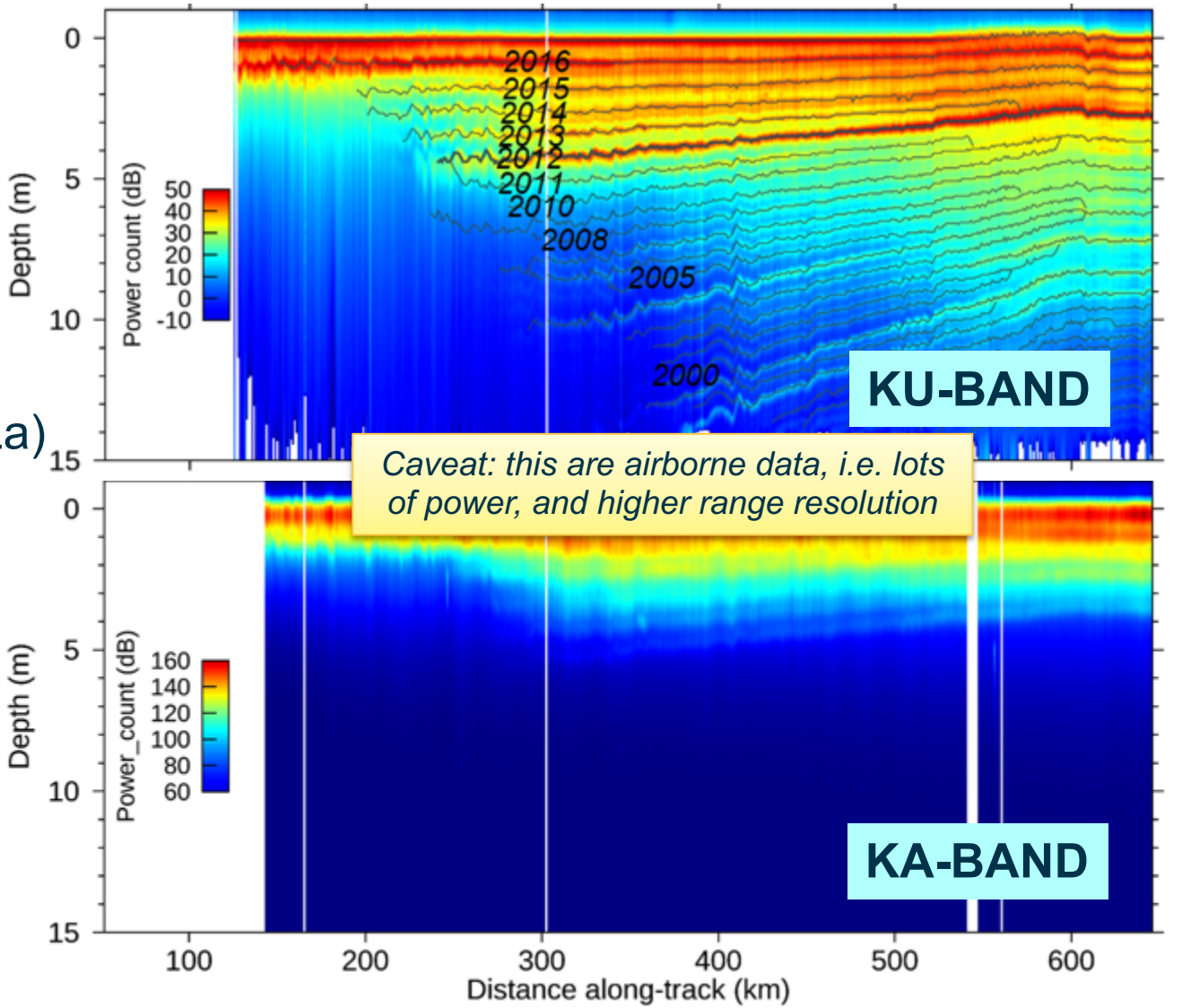
Otosaka, Shepherd, Casal et al.

CryoVEx campaigns
ASIRAS (Ku), KAREN(Ka), ALS(La)
+ Firn Cores
+ Firn Models

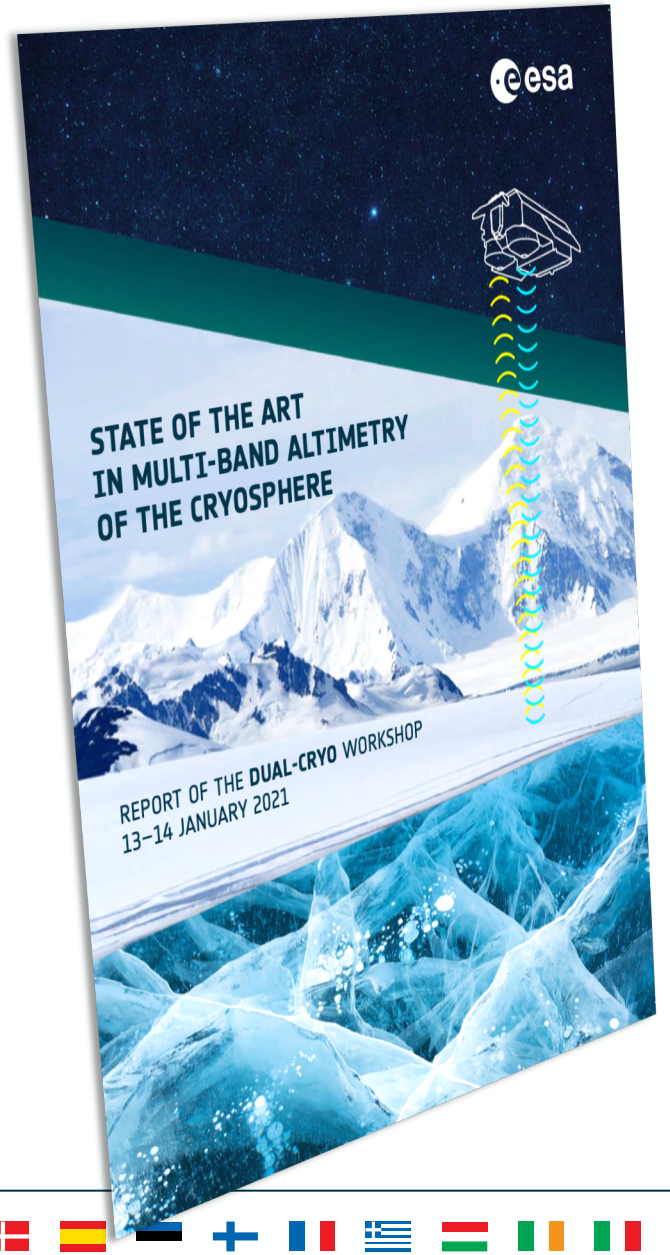
Ka band mostly picks the surface, Ku penetrates and shows the layers

Fluctuations in radar penetration are correlated with fluctuations in densities

CRISTALAir, a new Ku/Ka airborne demonstrator is being designed and commissioned **(1-GHz bandwidth, interferometric in both Ku an Ka)**



DUAL-CRYO report: the science of dual-band altimetry



P. Cipollini, G. March, A. Shepherd (eds.), “State of the art in multi-band altimetry of the cryosphere” , Report of the DUAL-CRYO Workshop, 13/14 January 2021. ESA reference ESA-EOPSM-CPTM-RP-4038, 32 pp.

(Google ‘DUAL-CRYO’)

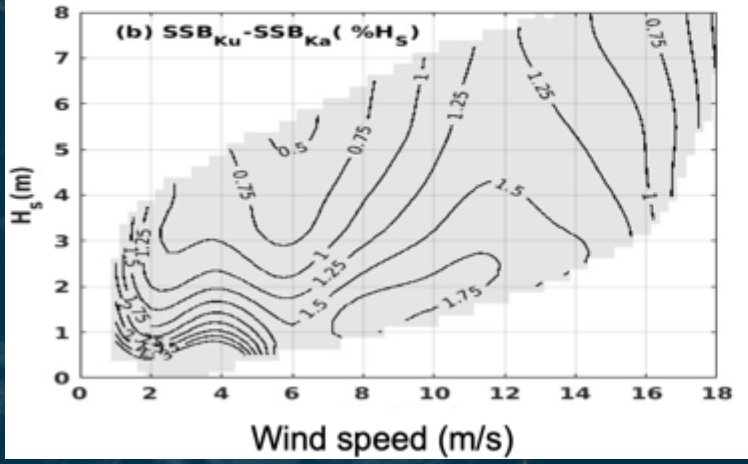
Ka/Ku: other opportunities

We are seeking the engagement and feedback from the polar and oceanographic communities to exploit the simultaneous Ku/Ka measurements for novel science.

For instance, how the dual-band capability is expected to enable new investigations in the marginal ice zone and in the coastal zone.

Example: a multi-frequency investigation of surface roughness-related effects like the Sea State Bias over the ocean, as seen in Doug Vandemark's talk

Mean SSB difference between Ka- and Ku-band altimeters



- Ka-band SSB is on avg. 1.2%*SWH **lower** than Ku-band
- Significant regional spatial variation in that value in a global avg. difference
- Ka-band matches V. et al. (2005) aircraft data quite well

D. Vandemark, OSTST 2022

And let's make CRISTAL even better….

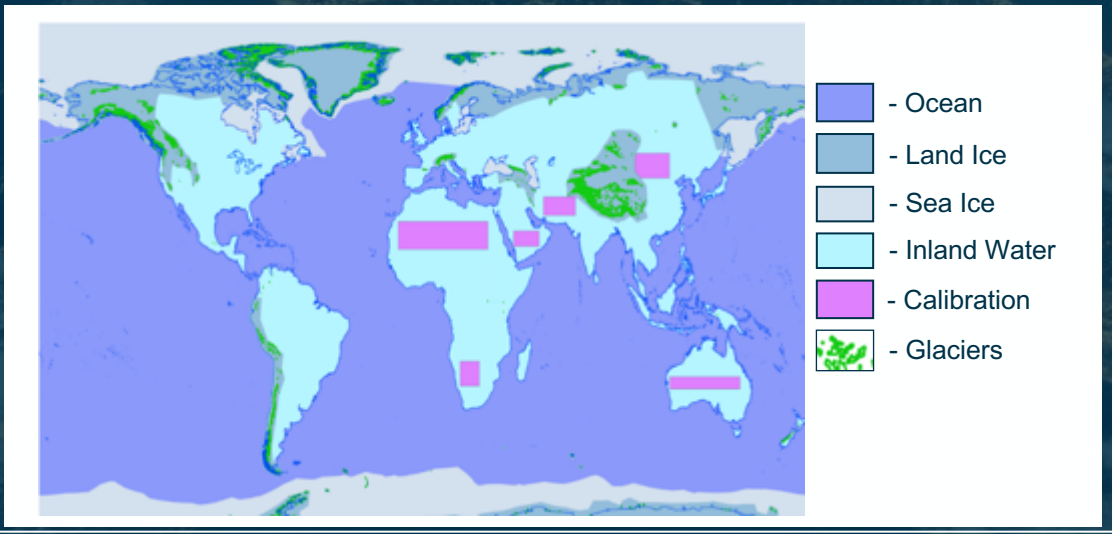
Increase the chirp bandwidth: 320 MHz → 500 MHz (both for Ku and Ka)

Increase interferometric baseline (1.17 m → 1.33 m) and reduce uncertainty in AoA to < 23 arcsec

Add the AMR-CR Advanced Microwave Radiometer for CRISTAL, provided by JPL and inherited from Sentinel-6 AMR-C)

- allowing wet tropospheric correction of altimeter measurements
- High frequency channels (HRMR) with small footprints (<4km) for coastal areas
- useful for ice classification and snow parameters (R&D needed)

Provide full coverage of hydrological targets



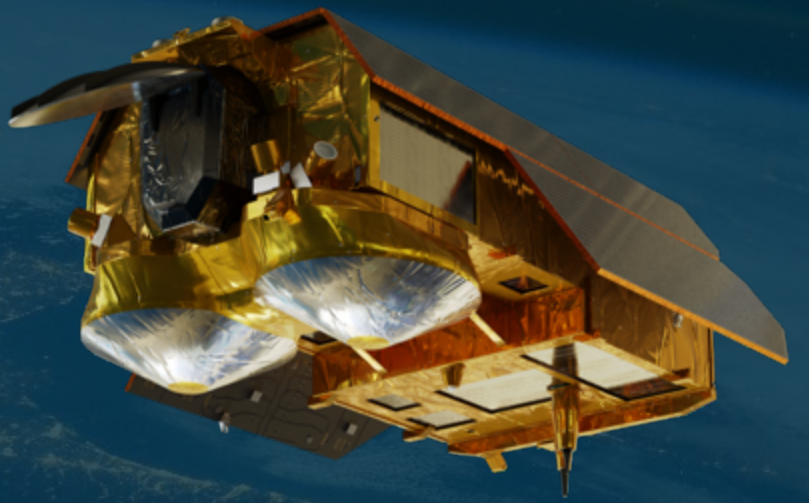
CRISTAL – a summary

Objectives: Monitor sea ice, icebergs, land ice, glaciers (primary), but also ocean, coasts and all inland waters

High inclination mission (92 deg), continues the legacy of CryoSat-2, with improved performance → *talk in Science IV session, Thurs pm*

Dual-frequency Ku/Ka SAR altimeter, Ku is interferometric

Improved bandwidth: 500 MHz in both Ku and Ka



- SARin over all ice surfaces
- Open burst over sea ice and icebergs → improved azimuth (along-track) resolution & range precision
- Flexible open loop/closed loop tracking everywhere
- AMR-CR radiometer with HRMR for oceanography, coastal altimetry, ice classification, snow parameters

Status: system PDR successfully completed early 2022 – Now in Phase C
On track for CRISTAL-A launch in 2027
(CRISTAL-B at some point in next decade)

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